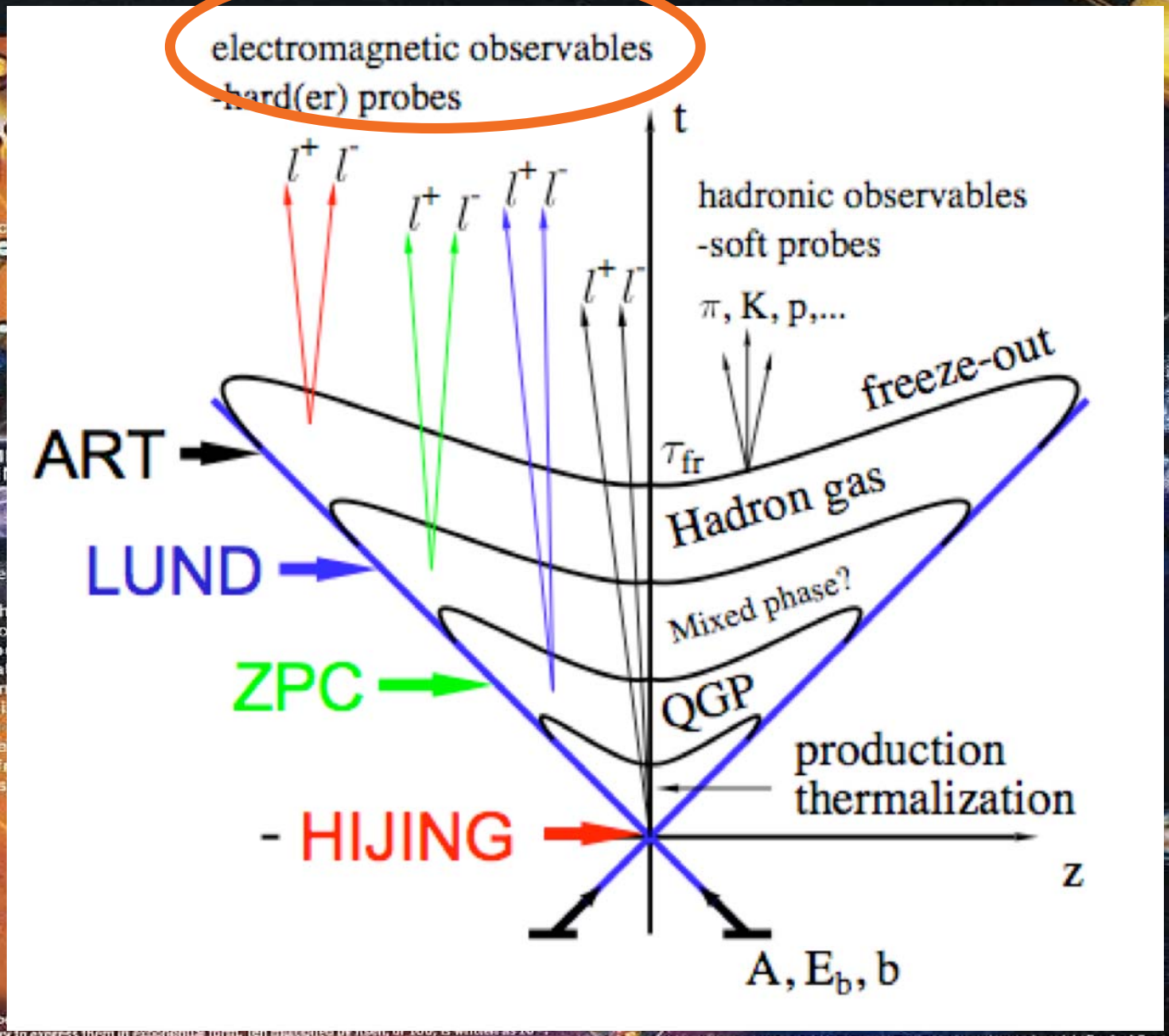
Nuclear Medium Effects on Heavy Flavor Production at RHIC

Xiaochun He

Georgia State University

Outline

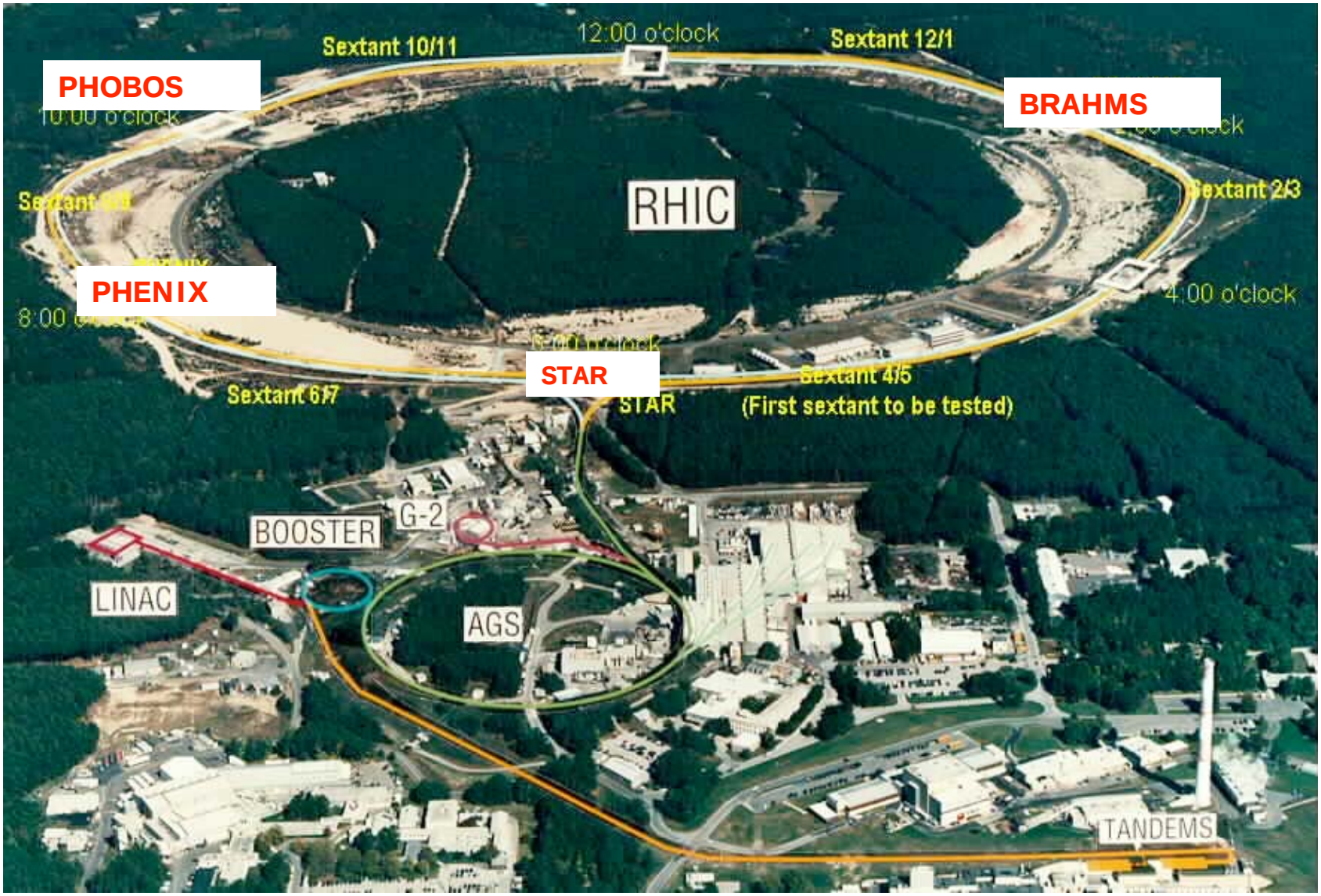
- Motivation
- RHIC Experiments
- Heavy Flavor Physics at RHIC
  - Open charm
  - J/ψ
- Direct Photon
- Summary and Outlook


electromagnetic observables
-hard(er) probes
t
hadronic observables
-soft probes
π, K, p,...
freeze-out
ART
τ_{fr}
Hadron gas
LUND
Mixed phase?
ZPC
QGP
production
thermalization
- HIJING
z
A, E_b, b

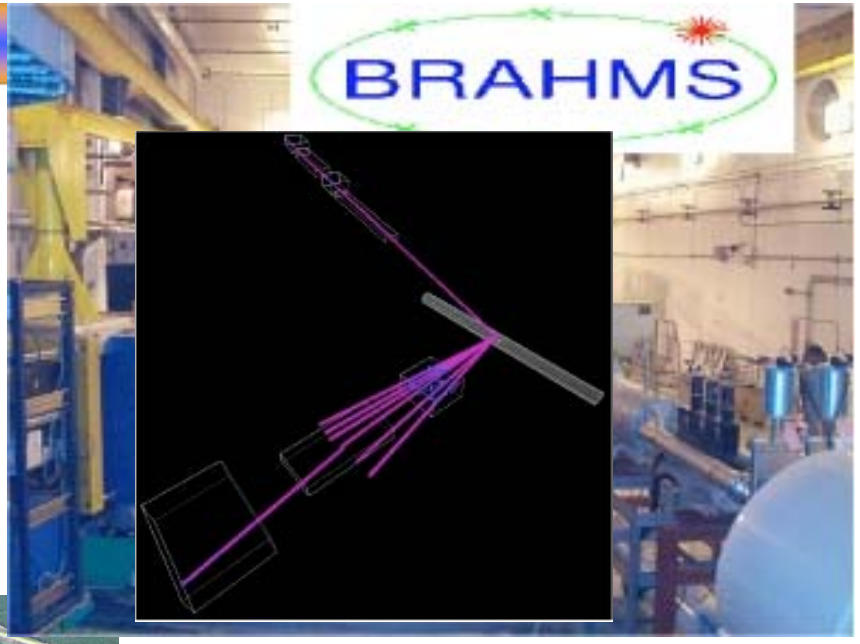
Work in a QCD Factory

- Create QCD matter
- Measure created particles
- Study **medium** effects on elementary QCD processes
- Understand the matter evolution at extreme high temperature and energy density (What is the temperature anyway?)

RHIC Experiments


PHOBOS
Sextant 10/11
12:00 o'clock
Sextant 12/1
BRAHMS
RHIC
PHENIX
4:00 o'clock
STAR
Sextant 6/7
STAR
Sextant 4/5
(First sextant to be tested)
BOOSTER
G-2
LINAC
AGS
TANDEMS


July 18, 2001
00:48:41
Run 7224
Event 5261
PHOBOS


BRAHMS


RHIC

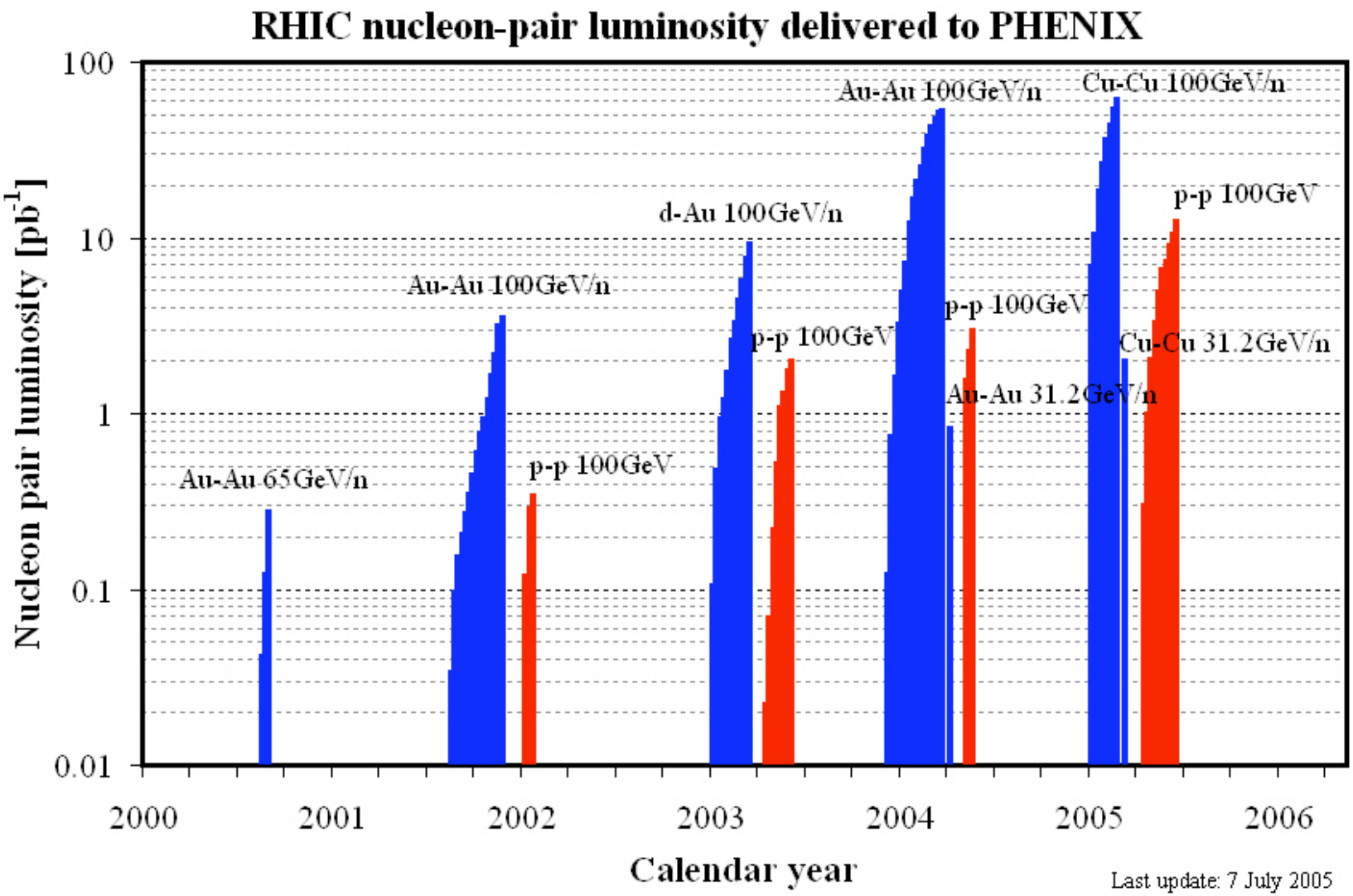

ENIX
PHENIX


STAR

RHIC Summary, Runs 01 - 05

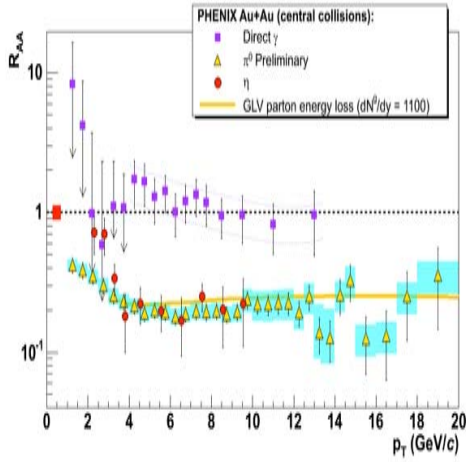
	Year			
	2001	Au-Au at 130 GeV/A	20 μb^{-1} (6 wks)	First look at RHIC collisions
	2001 – 2002	Au-Au at 200 GeV/A Comm./run pp at 200 GeV Au-Au at inj. E: 19 GeV/A	260 μb^{-1} (16wks) 1.4 pb^{-1} (5 wks) 0.4 μb^{-1} (1 day)	Global properties; particle spectra; first look at hard scattering. Comparison data and first spin run Global connection to SPS energy range
	2003	d-Au at 200 GeV/A pp at 200 GeV	74 nb^{-1} (10wks) 5 pb^{-1} (6 wks)	Comparison data for Au-Au analysis; low-x physics in cold nuclear matter Spin Development & Comparison data
	2004	Au-Au at 200 GeV/A Au-Au at 62 GeV/A pp at 200 GeV	3740 μb^{-1}(12wks) 67 μb^{-1} (3wks) 100 pb^{-1} (7wks)	"Long Run" for high statistics, rare events Energy Scan Spin Development: Commission jet target First measurements with longitudinal spin pol.
	2005	Cu-Cu at 200 GeV/A Cu-Cu at 62 GeV/A Cu-Cu at 22 GeV/A pp at 200 GeV pp at 410 GeV	42 nb^{-1} 8wks 1.5 nb^{-1} 12 days 18 μb^{-1} 39 hrs 30 pb^{-1} 10 wks 0.1 pb^{-1} 1 day	Comparison studies: surface/volume & impact parameter effects; Energy Scan Spin Development: Lum., Polarization First long data run for spin

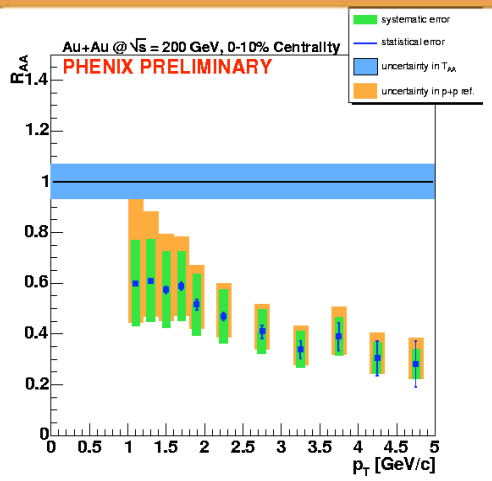
TIME 05, OCT 04TH 2005, ACHIM FRANZ, BNL

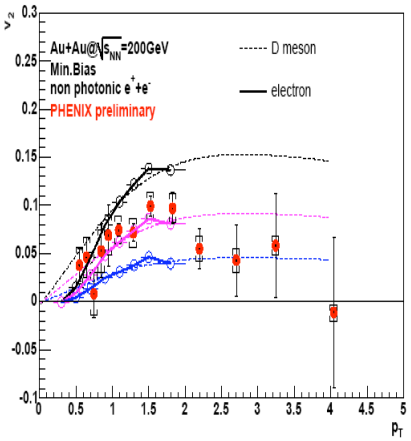


The nucleon-pair luminosity is defined as $\mathcal{L}_{NN} = A_1 A_2 L$, where $\mathcal{L}$ is the luminosity, and A_1 and A_2 are the number of nucleons of the ions in the two beam respectively.

Run6 Is Still Going







The matter is dense

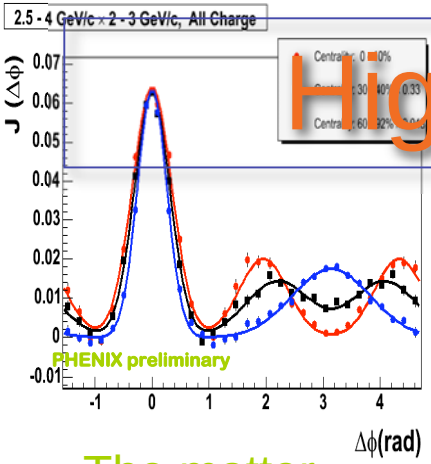
The matter is strongly coupled

Highlights from RHIC

$\varepsilon \cdot \tau \sim 5$ GeV/fm^2

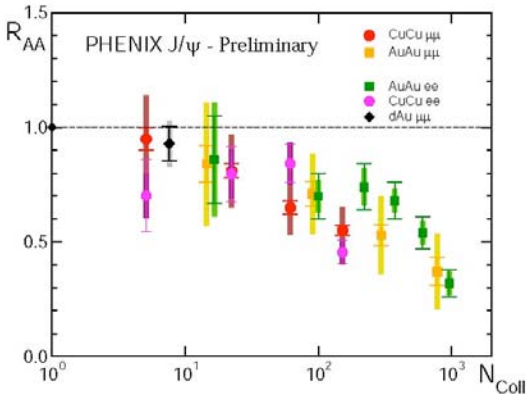
$dN_g/dy > 1100$

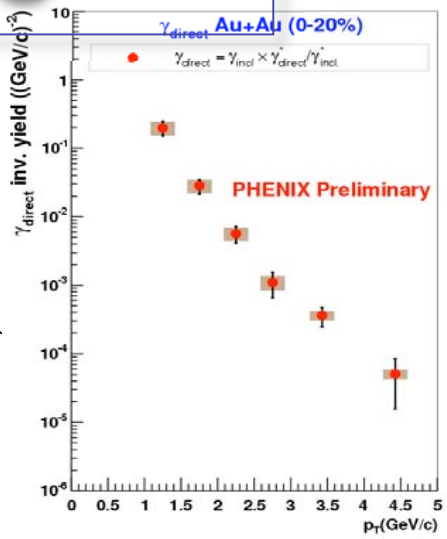
T_{ave} = 300 - 400 MeV (?)



The matter modifies jets

The matter may melt but regenerate J/ψ's



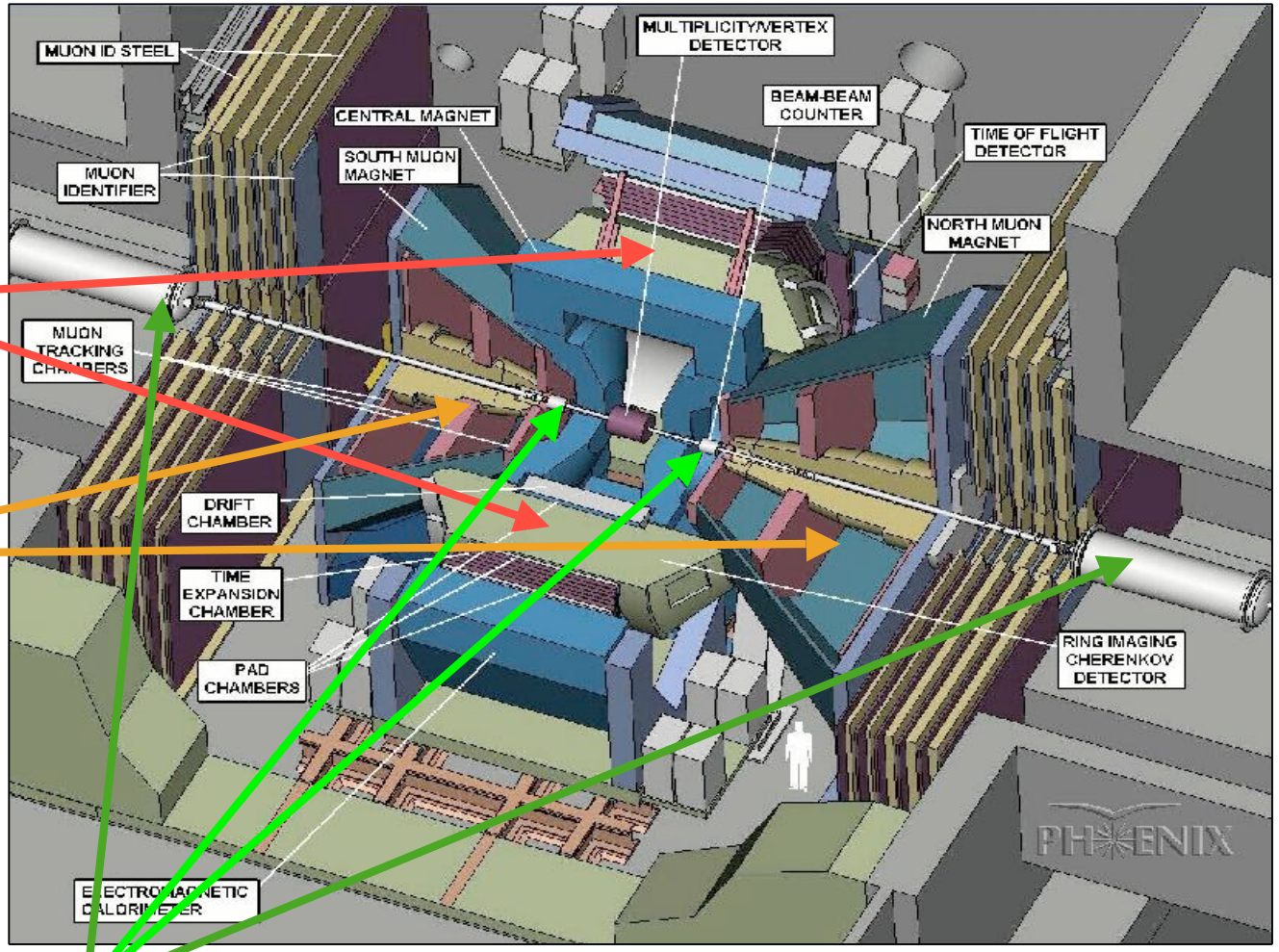


The matter is hot

OL

Central arms:
hadrons, photons,
Electrons:
$p > 0.2$ GeV/c
$|y| < 0.35$
$\Delta\phi = \pi$

Muon arms:
muons at forward rapidity
$p > 2$GeV/c
$1.2 < |y| < 2.4$
$\Delta\phi = 2\pi$



Centrality measurement:
We use beam beam counters together with zero degree calorimeters
Centrality is mapped to N_{part} (N_{col}) using Glauber model

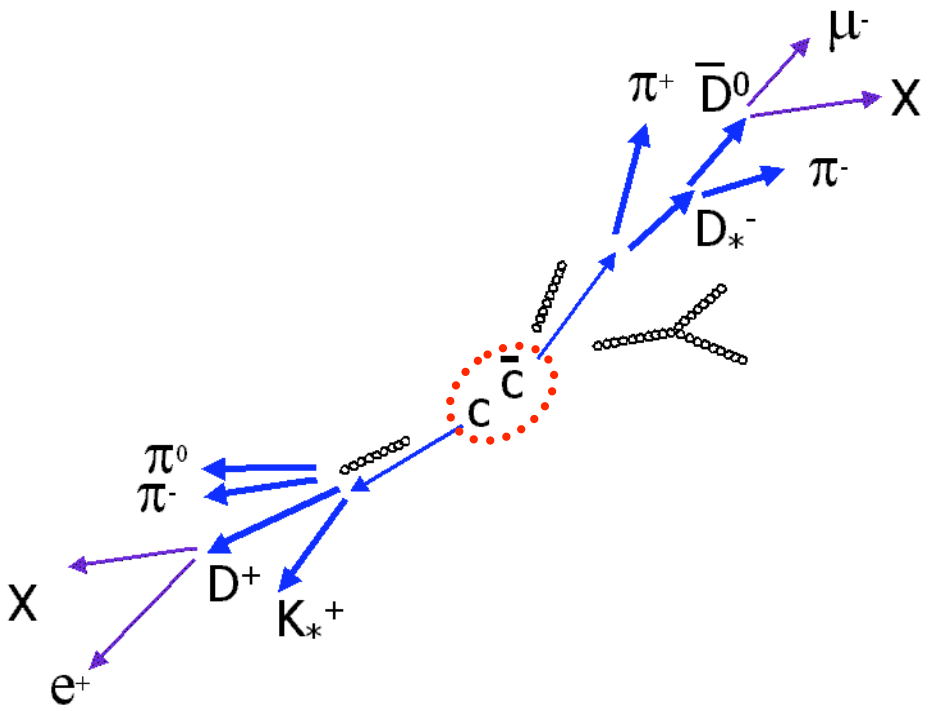
Heavy Quarks as **Medium** Probes

Heavy quarks (*c*, *b*) provide a hard scale via their mass which allow us to make comparison with pQCD. Three ways to make use of this:

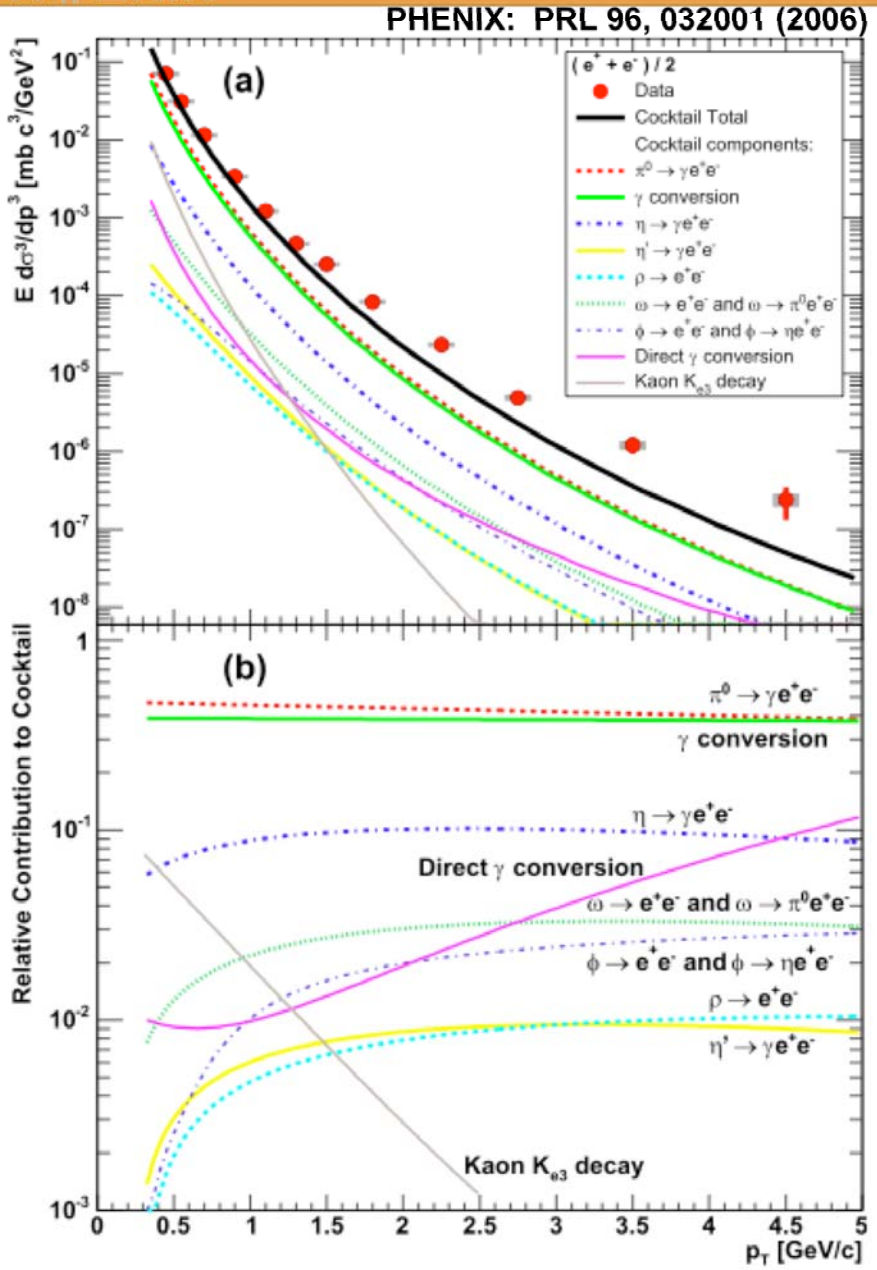
- ✓ Color screening of (Q-Qbar) bound states;
- ✓ Energy loss of "slow" heavy quarks (suppressed by "dead-cone" effect for $\theta < M/E$);
- ✓ D-, B-mesons as probes of collective flow.

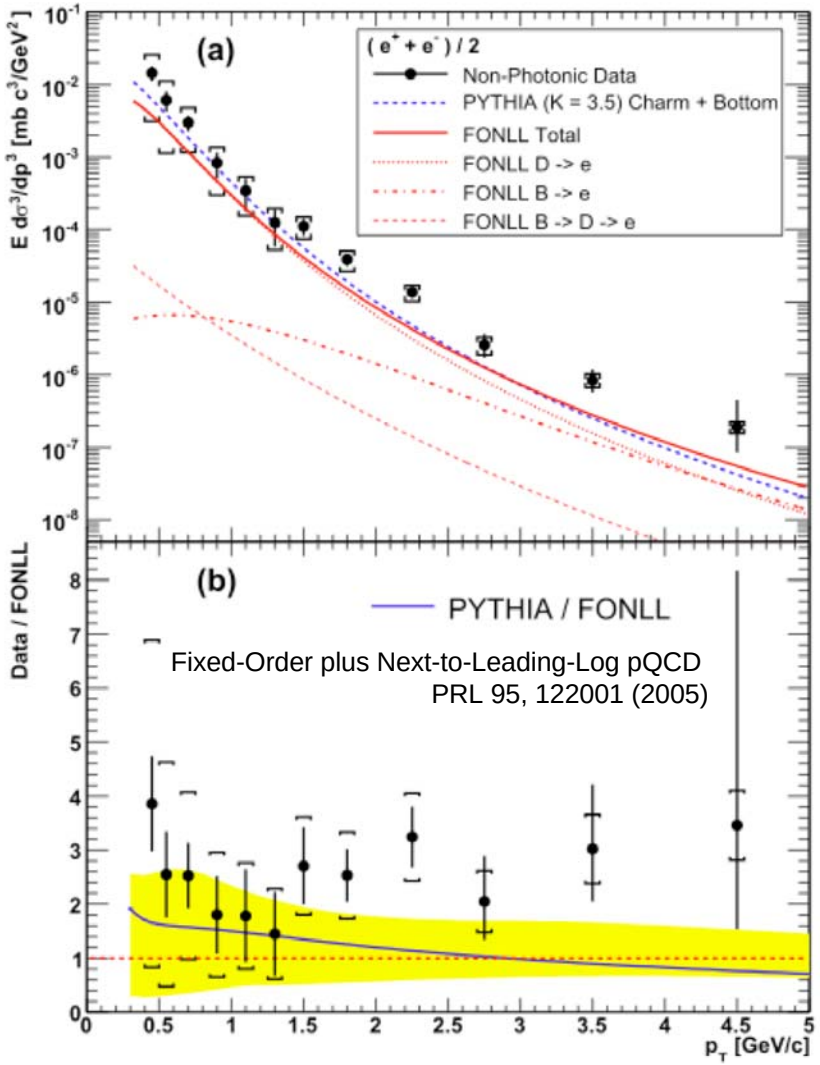
RHIC program: *c*-quarks and J/Ψ (and some *b*).

Open Charm

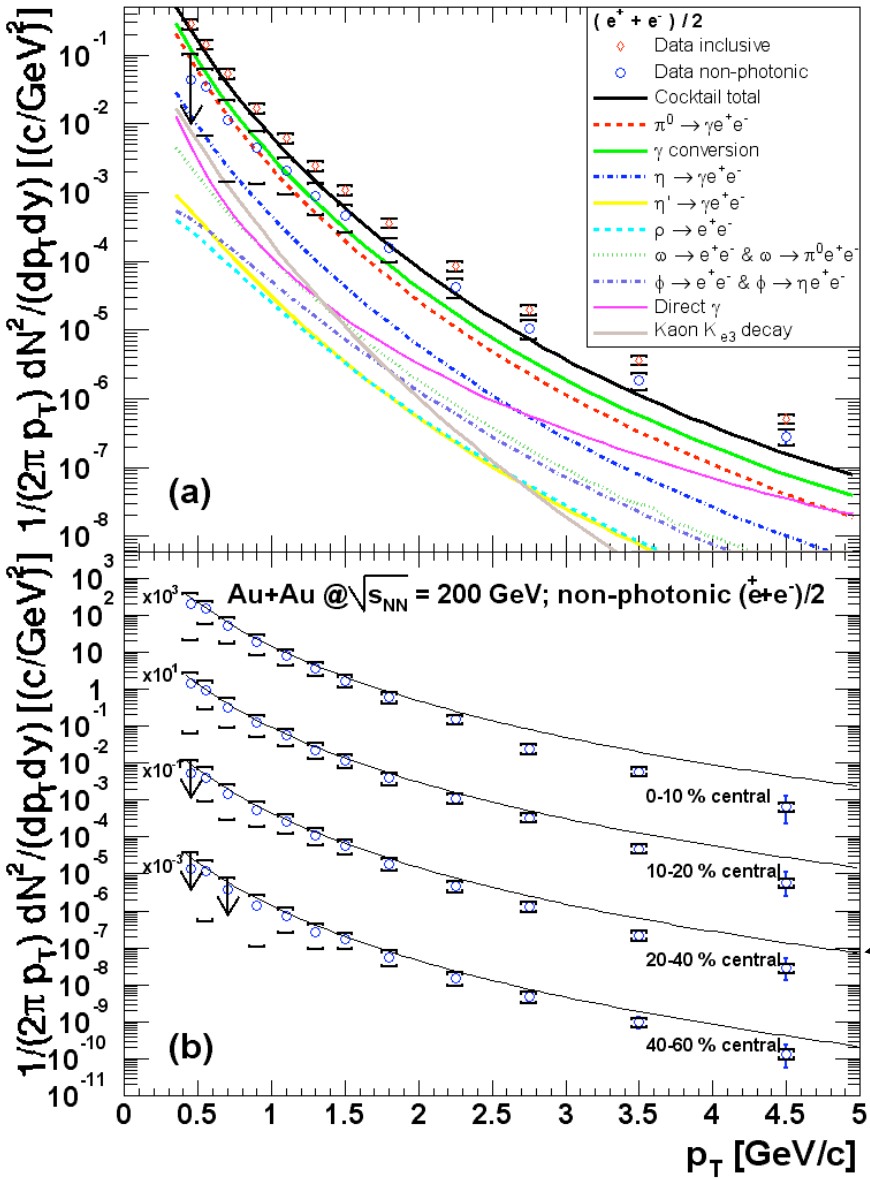


Inclusive electron Spectra from p+p at 200 GeV





PRL 96, 032301 (2006)



Inclusive non-photonic electron yields in Au+Au at 200 GeV

The spectra of electrons from heavy flavor decays were determined by subtracting cocktails of background contributions from other sources from the inclusive data. The most important background is the π^0 Dalitz decay.

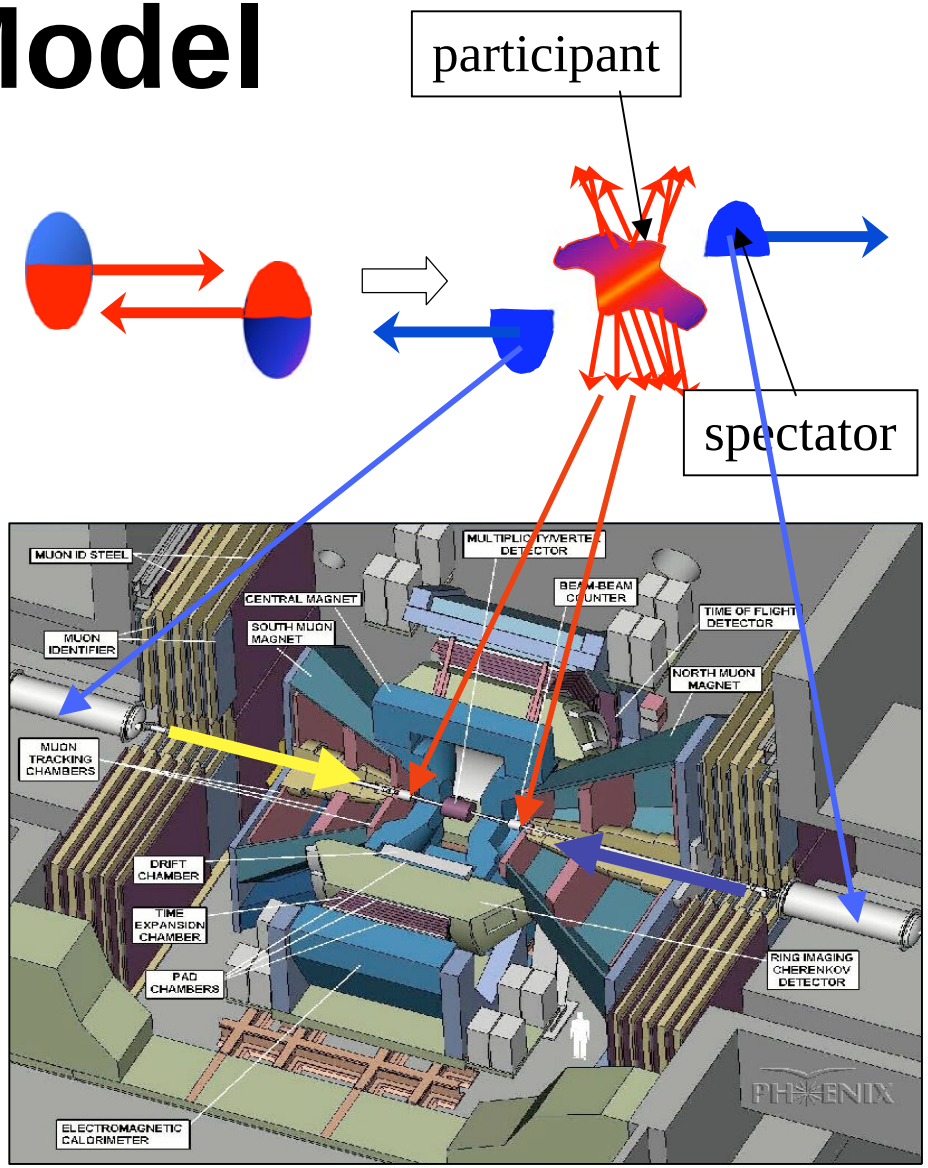
Most central collision

Different event centrality class

Less central collisions

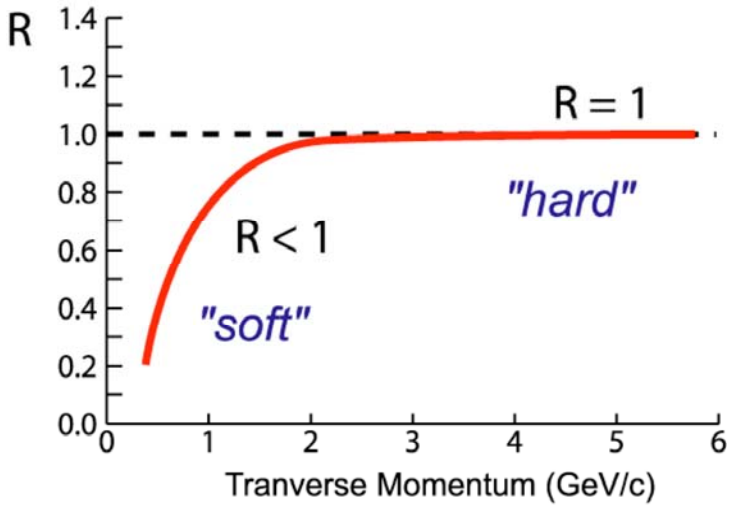
Participant Model

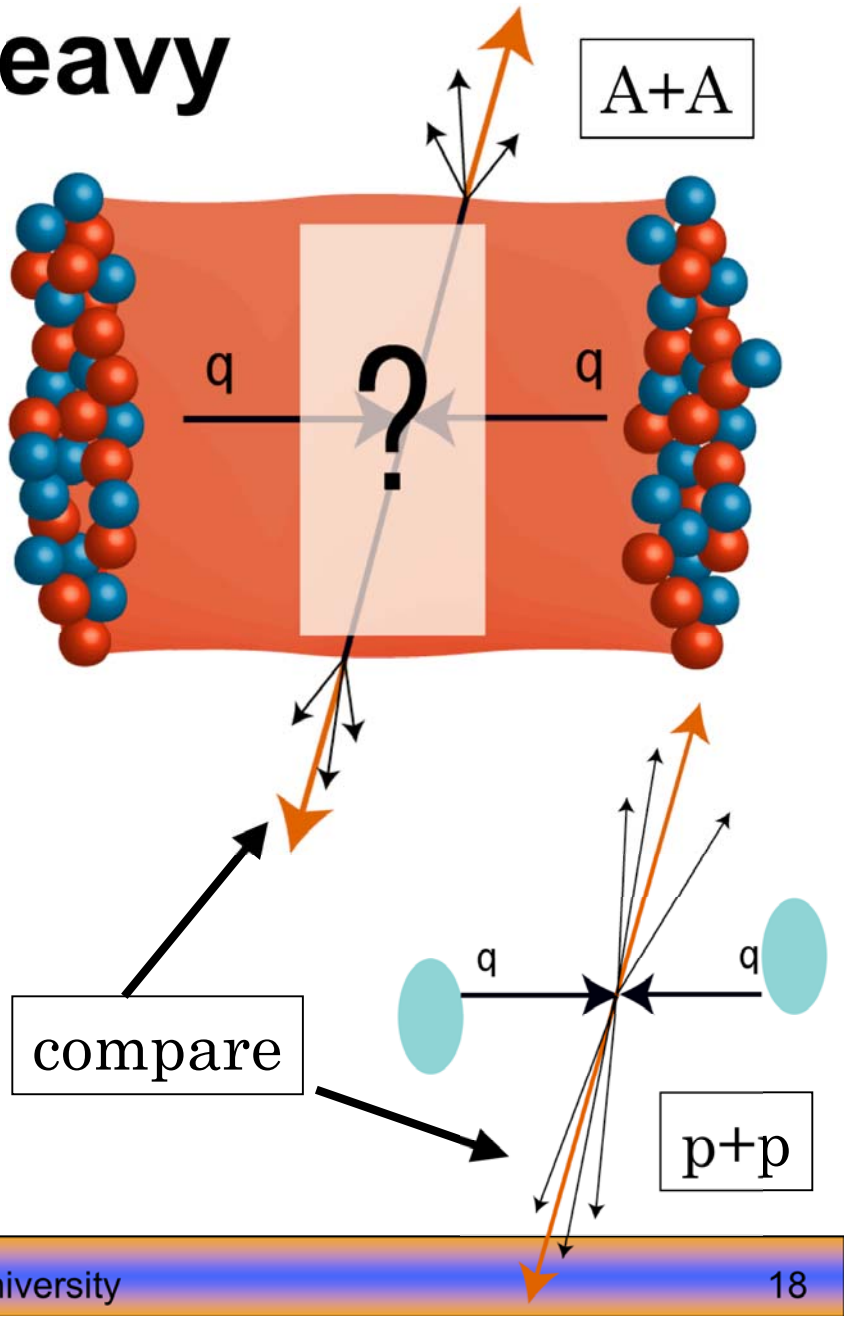
- **Participant and spectator**
  - *N*part: number of participant nucleons in collision
  - *N*coll: number of binary N-N collision
- **Centrality**
  - Determined with BBC and ZDC correlation
  - *N*part, *N*coll is obtained from MC with Galuber model.
  - 0%: central, 100%: peripheral collision



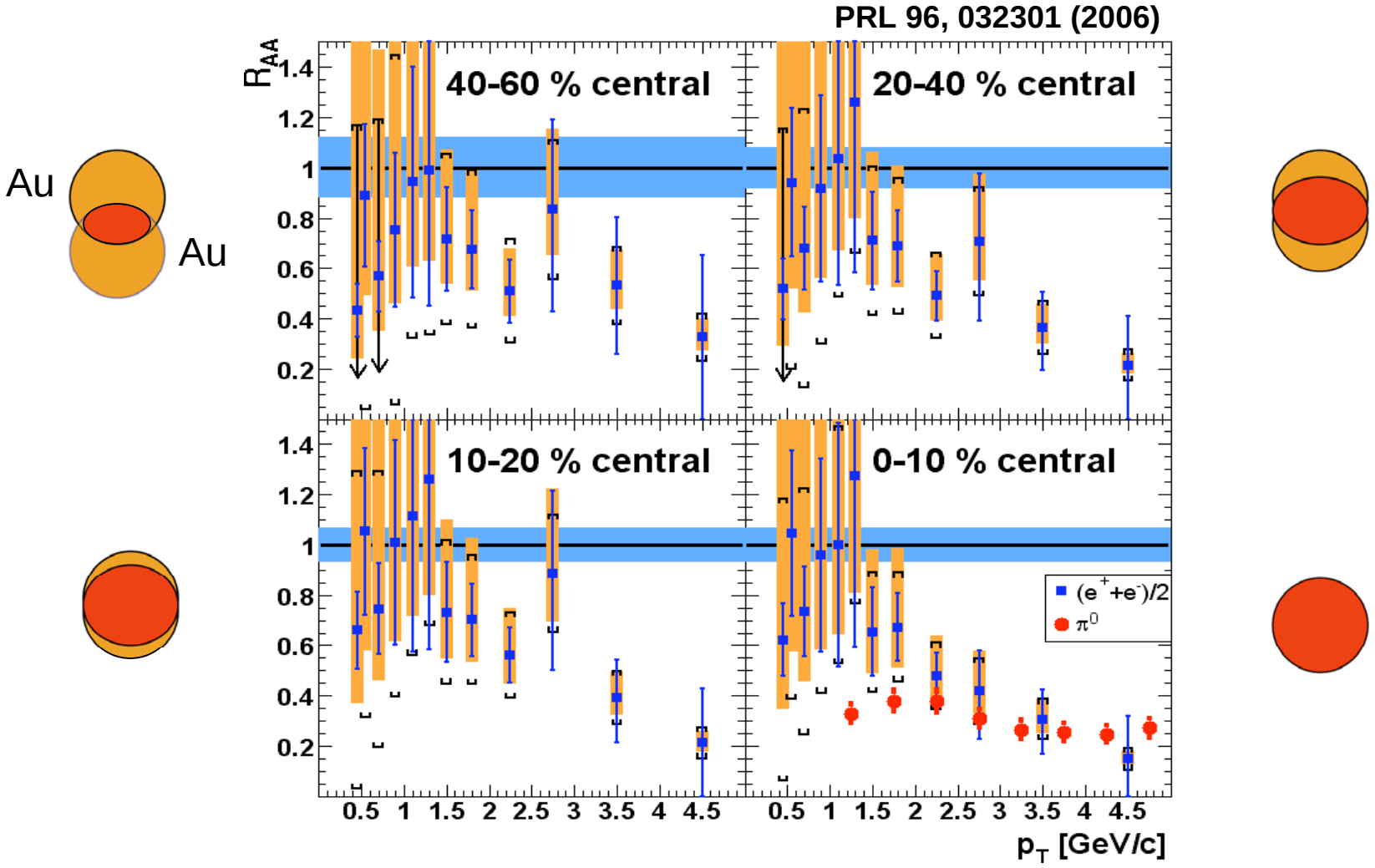
Medium Effects in Heavy Ion Collisions

$$R_{AA}(p_T) = \frac{d^2N^{AA}/dp_T d\eta}{T_{AA} d^2\sigma^{NN}/dp_T d\eta}$$



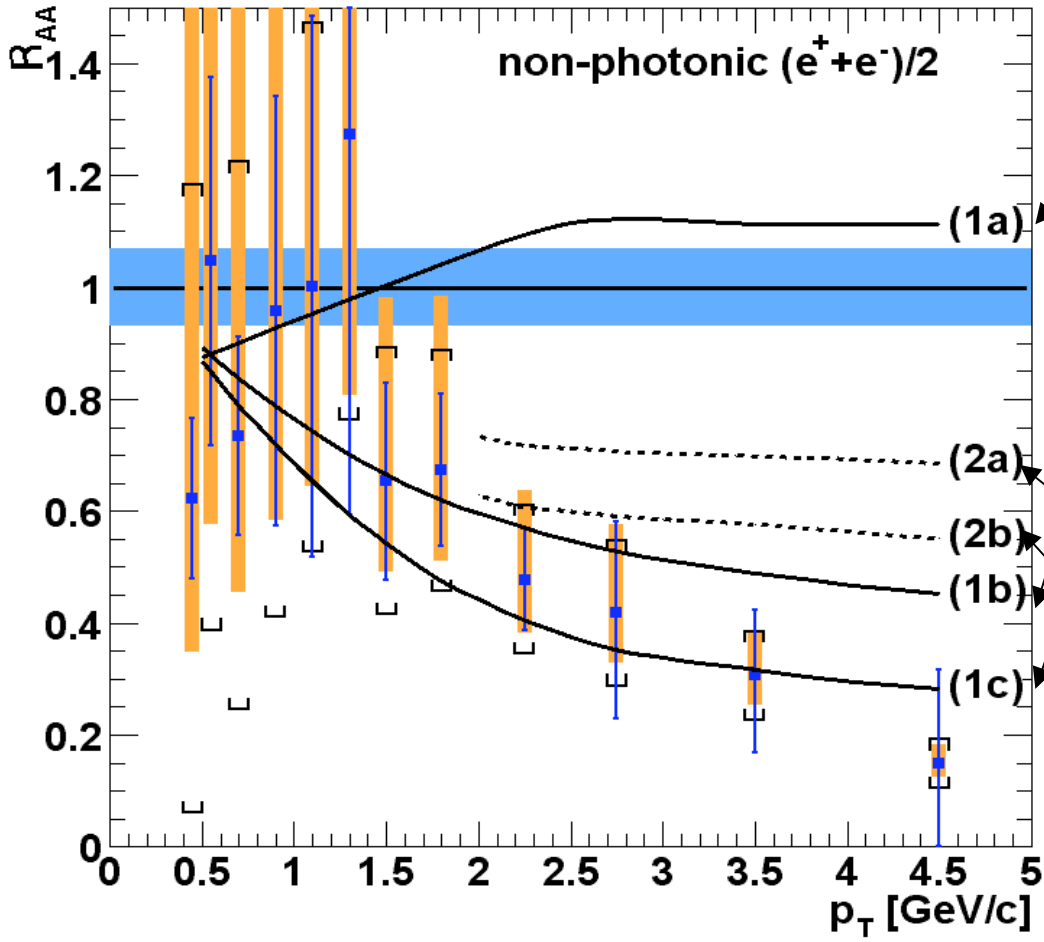


R_{AA} for e in Au+Au Collisions



Dense Medium: Theory Comparison

PRL 96, 032301 (2006)



(1a) $\hat{q} = 0\ \mathrm{GeV}^2/fm$

(1b) $\hat{q} = 4\ \mathrm{GeV}^2/fm$

(1c) $\hat{q} = 14\ \mathrm{GeV}^2/fm$

$\hat{q}$: proportional to the density of scattering centers in medium

PRD 71, 054027 (2006)

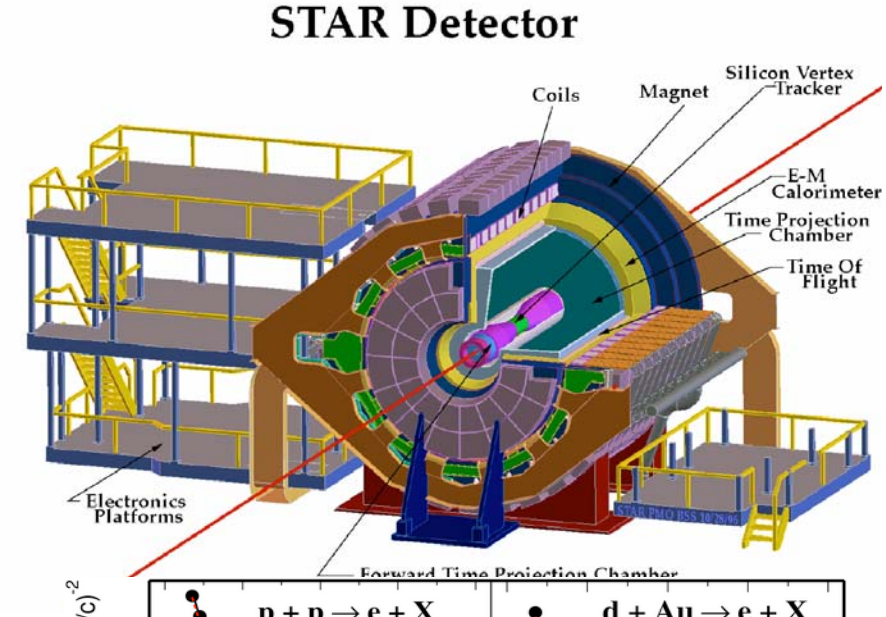
(2a) $dN_g/dy = 1000$

(2b) $dN_g/dy = 3500$

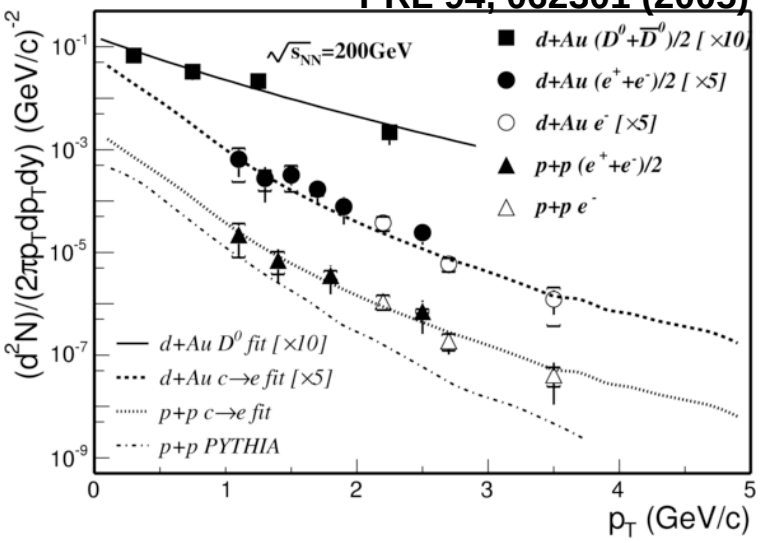
dN_g/dy : initial gluon density including decays from D & B

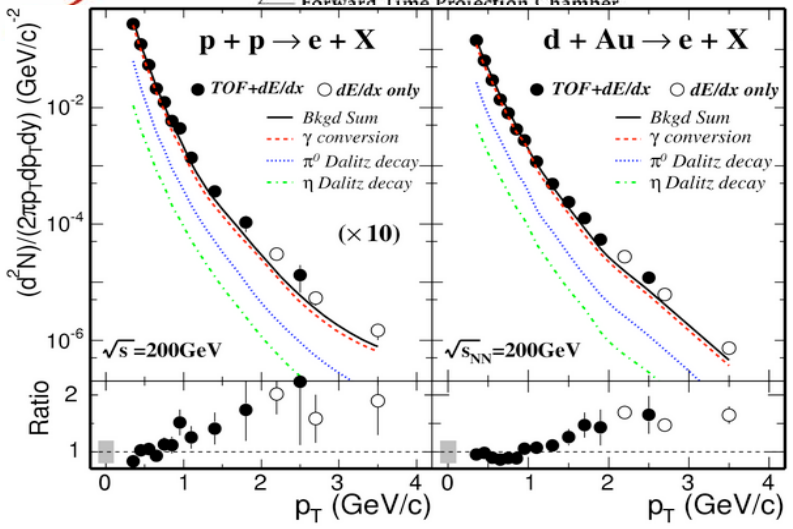
Phys. Lett , B 632, 81 (2006)

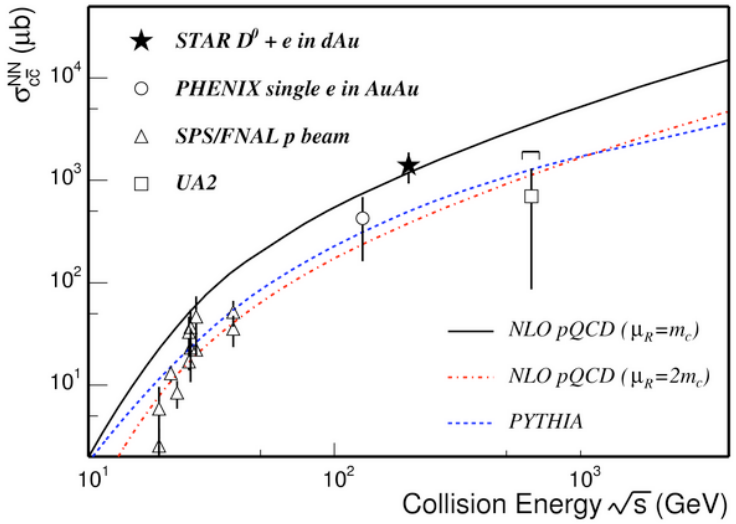
Direct Open Charm Measurement at RHIC



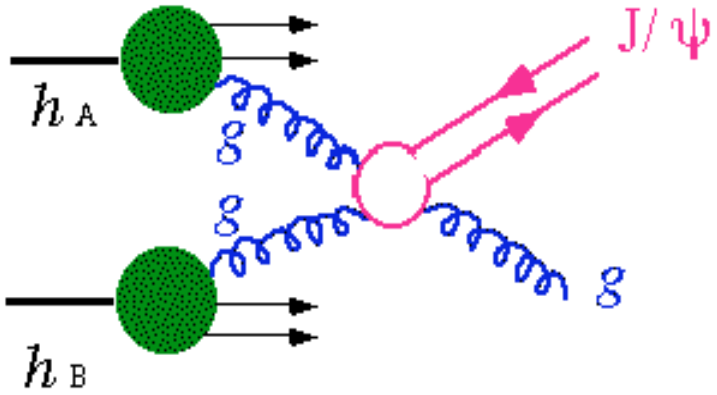
PRL 94, 062301 (2005)







J/Ψ Results from RHIC

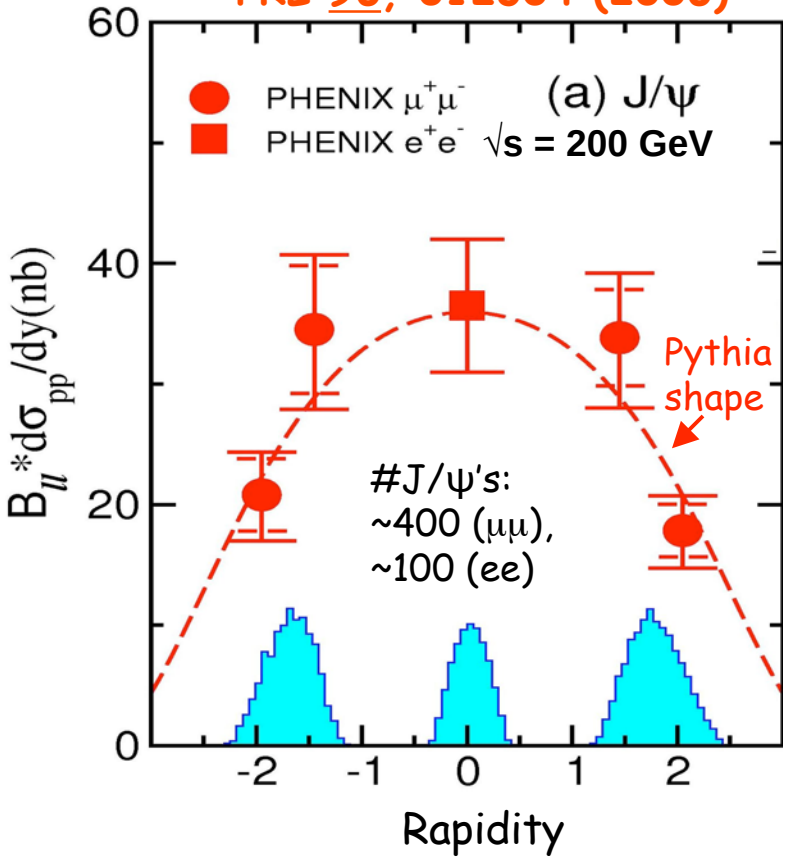


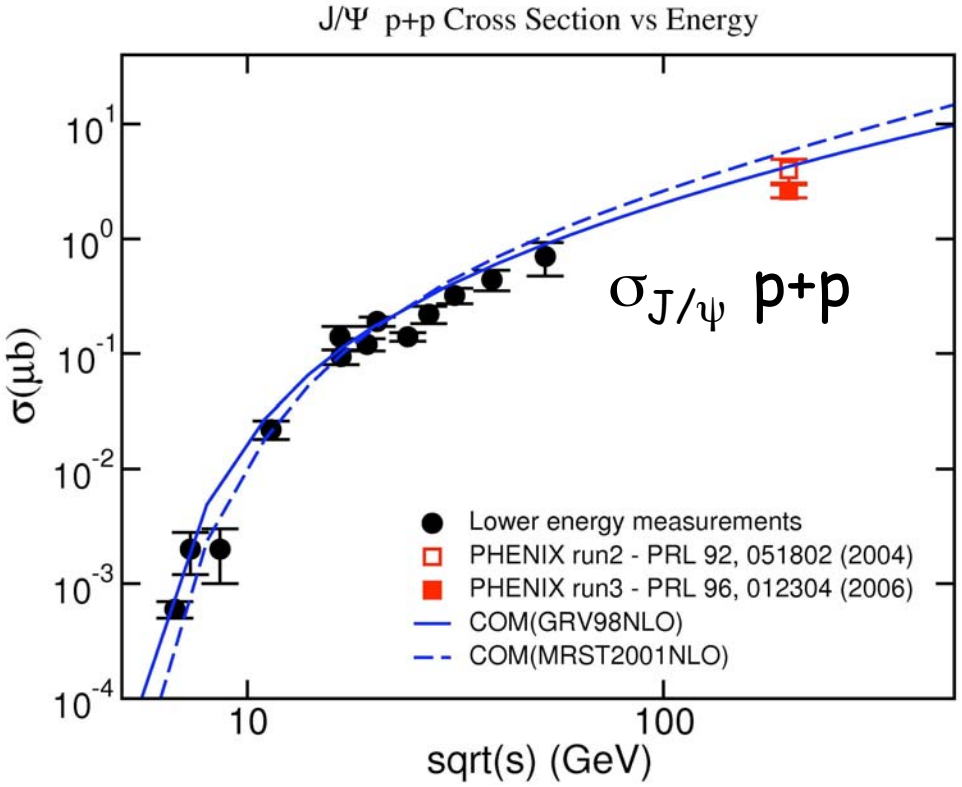
Why J/ψ?

- Gluon fusion dominates J/ψ production, however, several competing processes need to be clear up
  - Color singlet vs octet ccbar state
  - Feed-down from other ccbar resonance states
  - Other sources?
- What is the **medium** effects on J/ψ?

J/ψ Cross-section vs Rapidity & Energy

PRL 96, 012304 (2006)





More pp J/ψ's coming from PHENIX - ~5k/arm in 2005 run
(ψ' may be coming soon, at least for e^+e^-, but higher luminosities will be needed to get significant # of counts)

Cold Nuclear Medium Effects

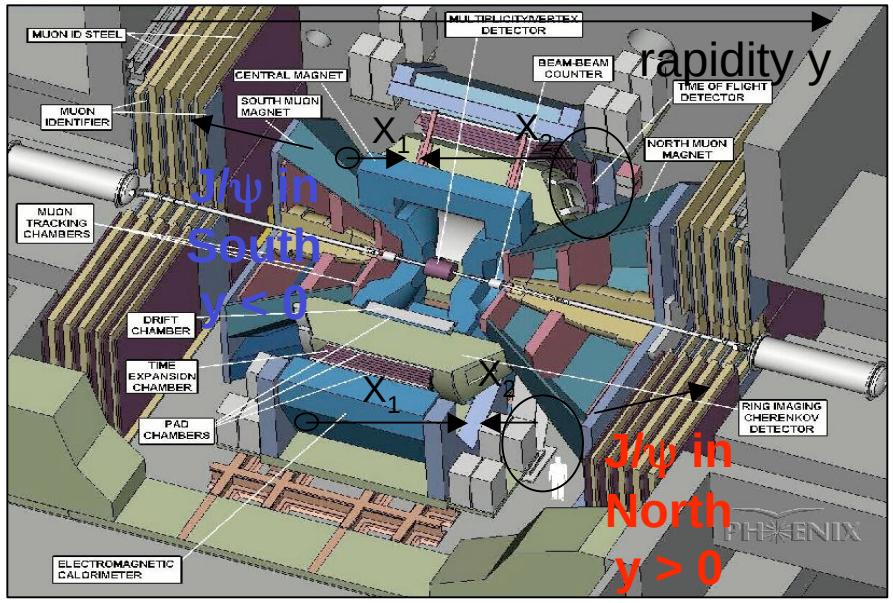
- Gluon (anti-)shadowing
- Nuclear absorption.
- Initial state energy loss.
- Cronin effect

South (y < -1.2) :
- large X_2 (in gold) ~ 0.090

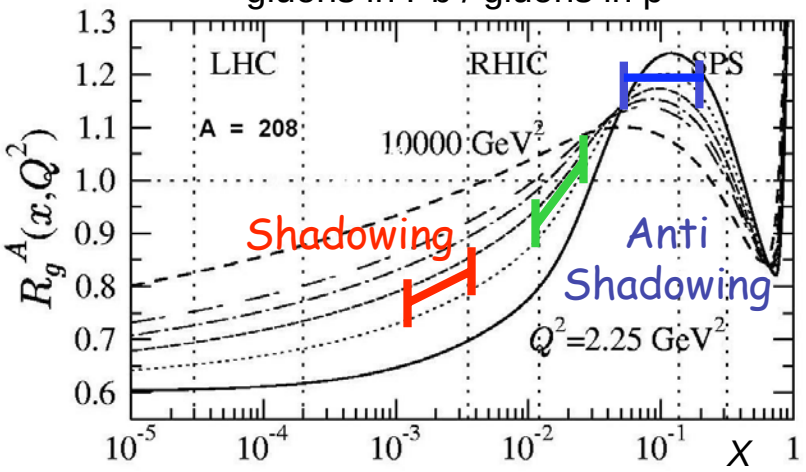
Central (y ~ 0) :
- intermediate X_2 ~ 0.020

North (y > 1.2) :
- small X_2 (in gold) ~ 0.003

Eskola, et al., Nucl. Phys. A696 (2001) 729-746.

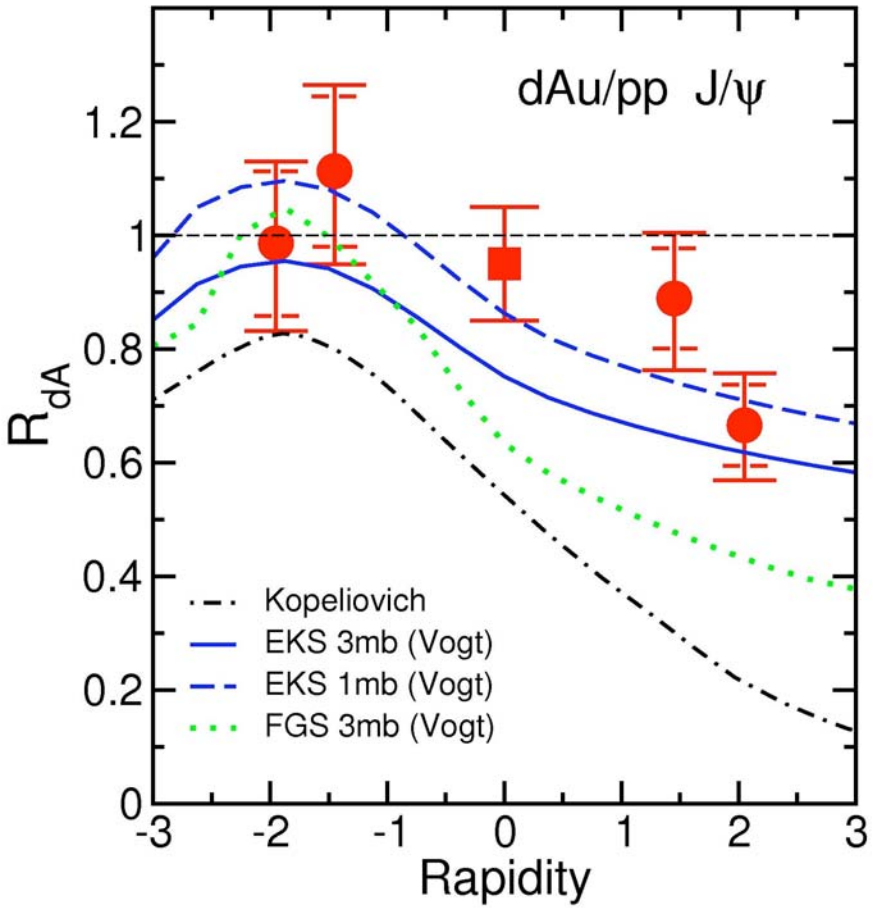


gluons in Pb / gluons in p



PHENIX J/ψ Nuclear Dependence for 200 GeV pp and dAu Collisions

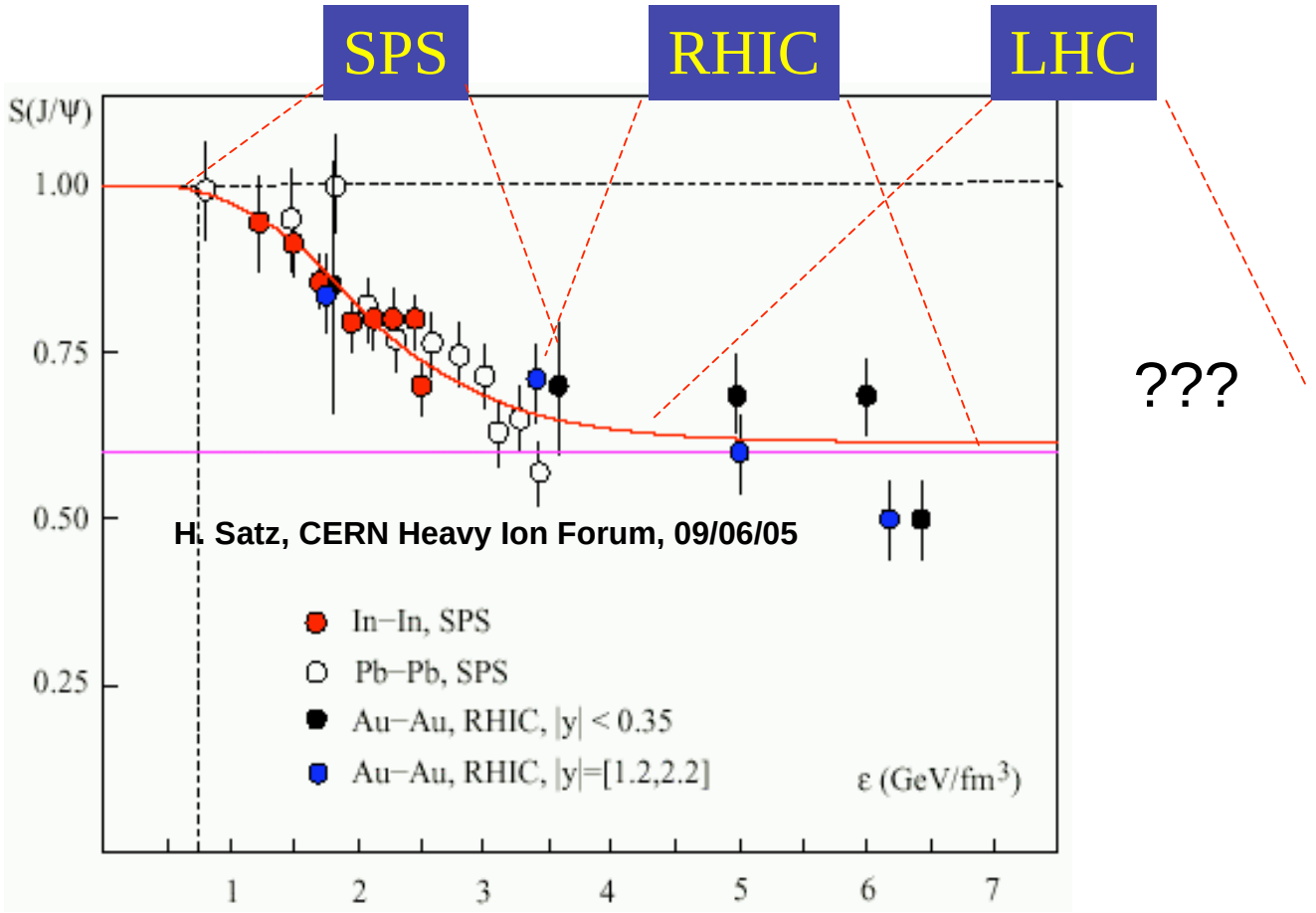
PRL 96, 012304 (2006)



- Data favors weak shadowing & absorption
- With limited statistics difficult to disentangle nuclear effects
- Will need another dAu run! (more pp data also)

Klein,Vogt, PRL 91:142301,2003
Kopeliovich, NP A696:669,2001

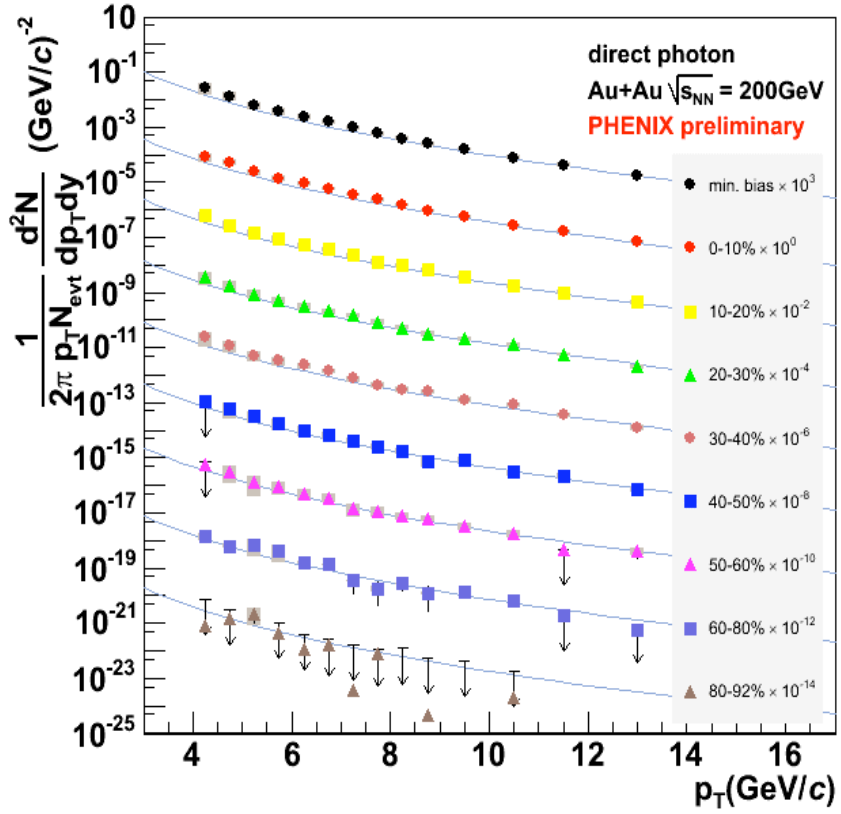
J/ψ Suppression Comparison



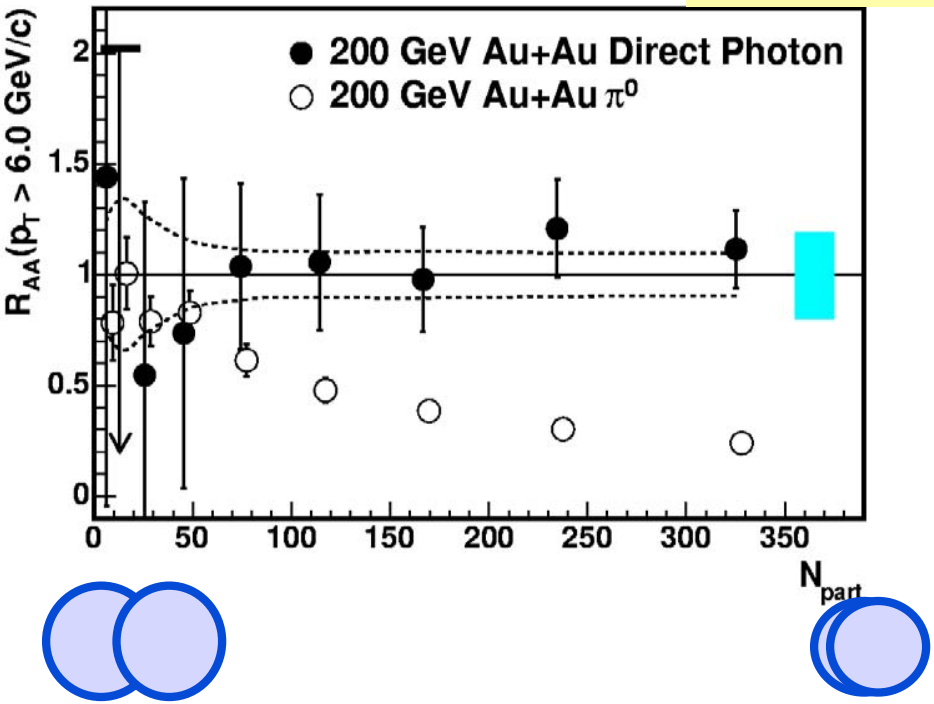
Direct γ from RHIC

Shining Photon: Baseline Measurement

NO direct photon suppression (initial state), and large π^0 suppression (final state)



Nuclear Modification factor $R_{AA} = \frac{dN_{AA}}{T_{AB} d\sigma_{pp}}$



S.S.Adler, et. al. (PHENIX Collaboration), PRL 94, 232301(2005)

Summary

Link to Slide 11

Outlook

More J/ψ Results Are Coming

- J/ψ polarization
- J/ψ v_2
- Bottomonium
- …

Thank You All

Backup Slides

RHIC-II - Quarkonia

- With detector upgrades (PHENIX and STAR):
  - J/ψ from B decays with displaced vertex measurement (both).
  - Reduce $J/\psi \rightarrow \mu\mu$ background with forward μ trigger in PHENIX.
  - Improve mass resolution for charmonium and resolve Υ family.
  - See γ in forward calorimeter in front of muon arms (PHENIX) and in FMD in STAR
- And with the luminosity upgrade:
  - J/ψ R_{AA} to high p_T. Does J/ψ suppression go away at high p_T?
  - J/ψ v_2 measurements versus p_T. See evidence of charm recombination?
  - Υ R_{AA}. Which Upsilons are suppressed at RHIC?
  - Measure $\chi_c \rightarrow J/\psi + \gamma$ R_{AA}. Ratio to J/ψ?
  - Measure ψ' R_{AA}. Ratio to J/ψ?
  - Measure $B \rightarrow J/\psi$ using displaced vertex - independent B yield measurement, also get background to prompt J/ψ measurement.

From Mike Leitch, SQM2006

Temperature	New Particles	$4N(T)$
$T < m_e$	γ's + ν's	29
$m_e < T < m_\mu$	$e^\pm$	43
$m_\mu < T < m_\pi$	$\mu^\pm$	57
$m_\pi < T < T_c$ [†]	π's	69
$T_c < T < m_{\text{strange}}$	π's + $u, \bar{u}, d, \bar{d}$ + gluons	205
$m_s < T < m_{\text{charm}}$	$s, \bar{s}$	247
$m_c < T < m_\tau$	$c, \bar{c}$	289
$m_\tau < T < m_{\text{bottom}}$	$\tau^\pm$	303
$m_b < T < m_{\text{W,Z}}$	$b, \bar{b}$	345
$m_{W,Z} < T < m_{\text{Higgs}}$	$W^\pm, Z$	381
$m_H < T < m_{\text{top}}$	H^0	385
$m_t < T$	$t, \bar{t}$	427

Tc corresponds to the confinement-deconfinement transition between quarks and hadrons.

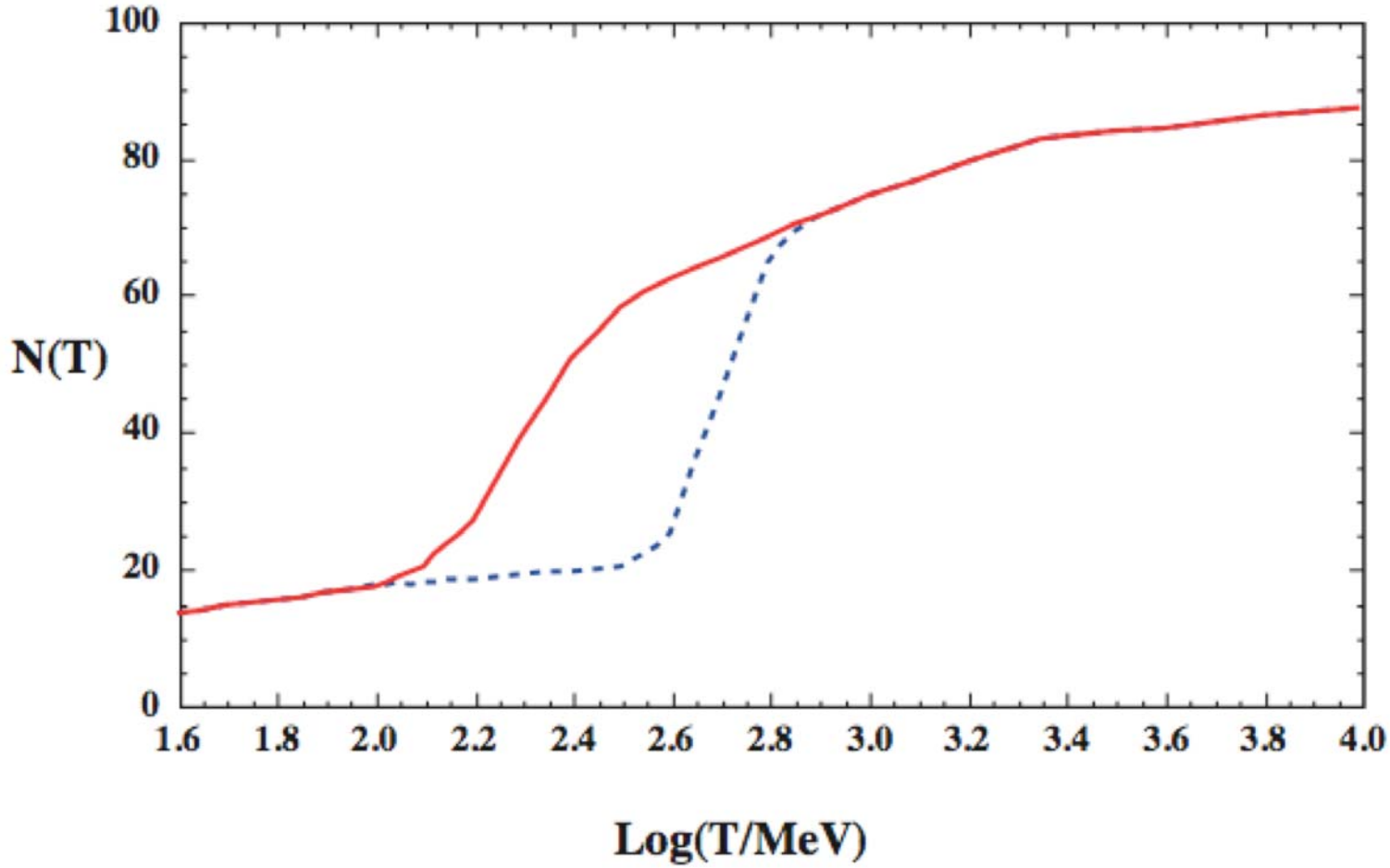
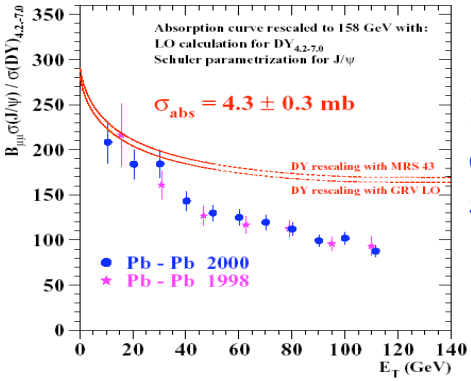


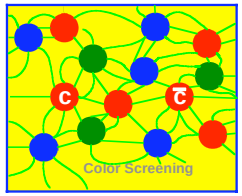
Figure 19.3: The effective numbers of relativistic degrees of freedom as a function of temperature. The sharp drop corresponds to the quark-hadron transition. The solid curve assume a QCD scale of 150 MeV, while the dashed curve assumes 450 MeV.

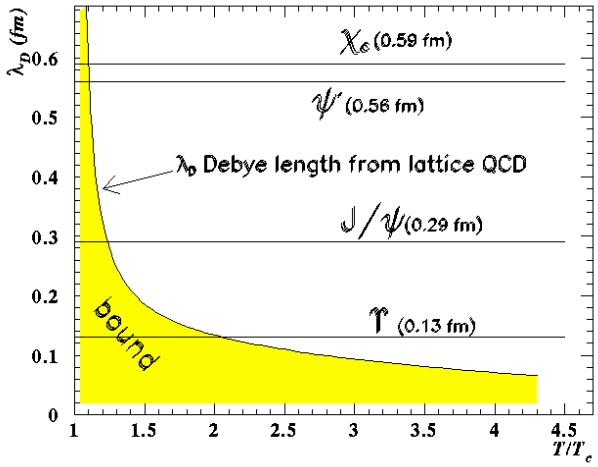
AuAu J/ψ's - Quark Gluon Plasma (QGP) signature?

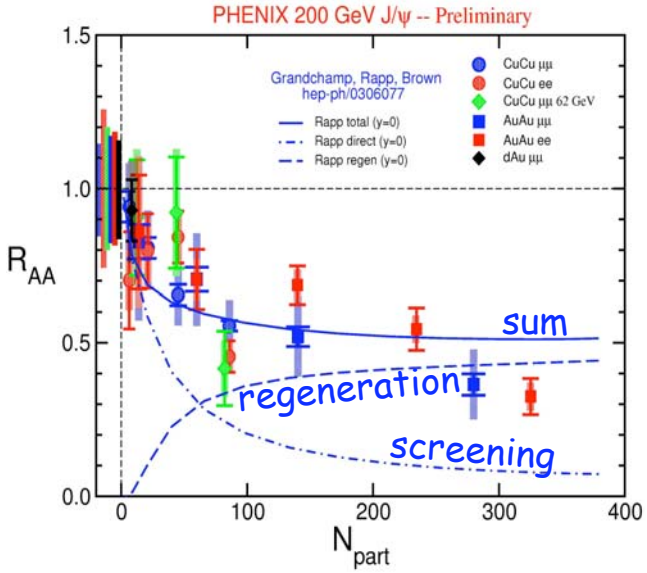
Debye screening predicted to destroy J/ψ's in a QGP with different states "melting" at different temperatures due to different binding energies.



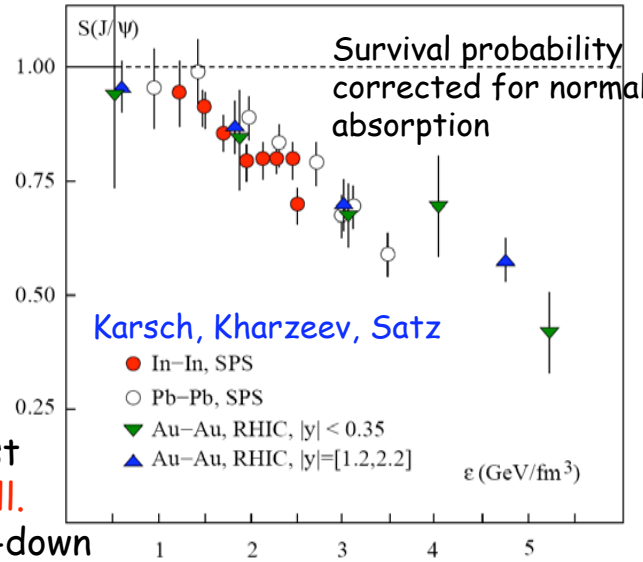
NA50 anomalous suppression







but recent regeneration models might give enhancement that compensates for screening?



on the other hand, recent lattice calculations suggest J/ψ not screened after all. Suppression only via feed-down from screened χ_c & ψ'